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Interpretation (or is it Calibration?) of Rayleigh-Scatter Lidar Signals

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Interpretation (or is it Calibration?) of Rayleigh-Scatter Lidar Signals

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Physics & CASS

Utah State University

www.usurayleighlidar.com

CEDAR Workshop

University of Seattle, WA

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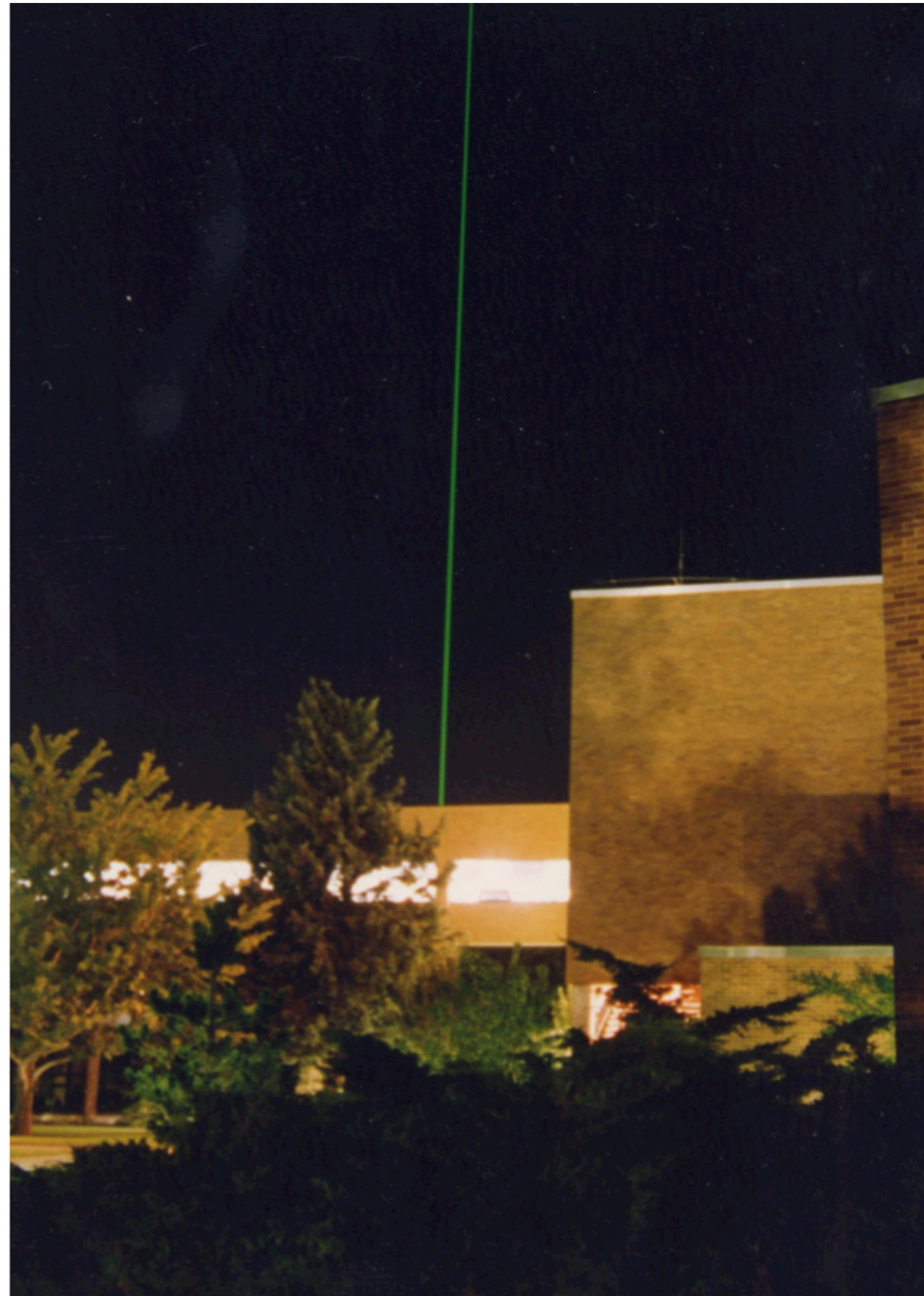
Green Beam of the Rayleigh Lidar above USU

Relative Densities

Absolute Temperatures



Upgraded Rayleigh Lidar at USU

Two lasers

Four 1.25-m mirrors

[Photo by Thomas Amely, 2012]

Signal & Relative Density

- **Signal is derived from the observed signal + background $(S+B)_{Obs}$ minus the observed background B_{Obs}**

$$S = (S+B)_{Obs} - B_{Obs}$$

- **Background comes from**
    - **backscattered city lights**
    - **star light**
    - **moon light**
    - **PMT thermionic emission**

- **Neutral number density is proportional to the signal times range squared. Obtain a relative density,**

$$n(r) \propto S(r)\, r^2$$

Temperature Equation

- **Combine Hydrostatic Equilibrium, and**

$$\frac{dP}{dh} + n(h)m(h)g(h) = 0$$

- **Ideal Gas Law to find the**

$$P(h) = n(h)kT(h)$$

- **Temperature Equation used in the data reduction**

$$T(h) = T(h_0)\frac{n(h_0)}{n(h)} + \frac{1}{k}\int_h^{h_0} \frac{n(h')}{n(h)} m(h')g(h')\,dh'$$

We will refer to terms in this equation in the next few slides.

How to Interpret (Calibrate) the Data

Simulate the Data & Experiment

- **Start with a temperature profile and a corresponding density profile, e.g., from an MSIS or CIRA model**

- **Convert density to signal** $S(r) = \text{const}\; n(r)/r^2$**, where** “const” **is a constant that gives a signal similar to the observed photon count rate.**
  - In some cases work with the signal
  - In some cases add a background
  - Because of photon counting, have Poisson statistics

- **Perform the data reduction steps, starting with the signal or the signal + background and separate background**
  - Impose a known error
  - Find its effect

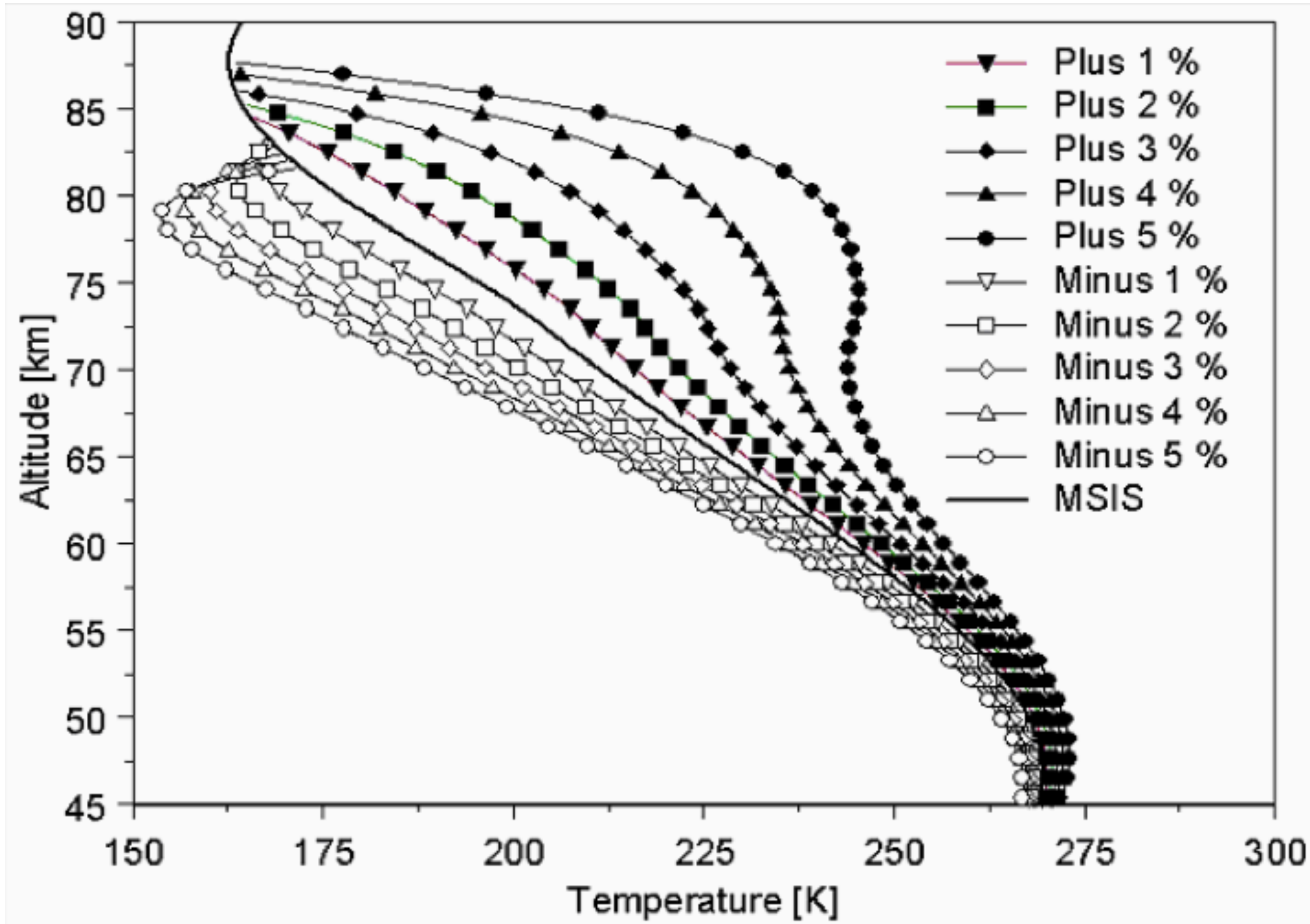
Evaluate the Background Correctly

Start at the altitude where the signal is 16 times one σ.

If the evaluated background is too small, the starting altitude is high and the derived temperatures are too big and are distorted.

If the evaluated background is too big, the starting altitude is low and the derived temperatures are too small and are distorted.

Initial and Derived Temperatures



To minimize this problem, we observe and average many, many background samples.

[Herron, 2004]

Temperature Derivation

- **Temperature Equation**

$$T(h) = T(h_0)\frac{n(h_0)}{n(h)} + \frac{1}{k}\int_h^{h_0} \frac{n(h')}{n(h)} m(h')g(h')\,dh'$$

- **Assume turbulent mixing of N_2 and O_2**
    - Mean mass $m(h)$ is constant
    - Derive relative densities from observations
    - Need $g(h)$
    - Need the initial temperature, T_0, the temperature at the highest altitude, h_0.

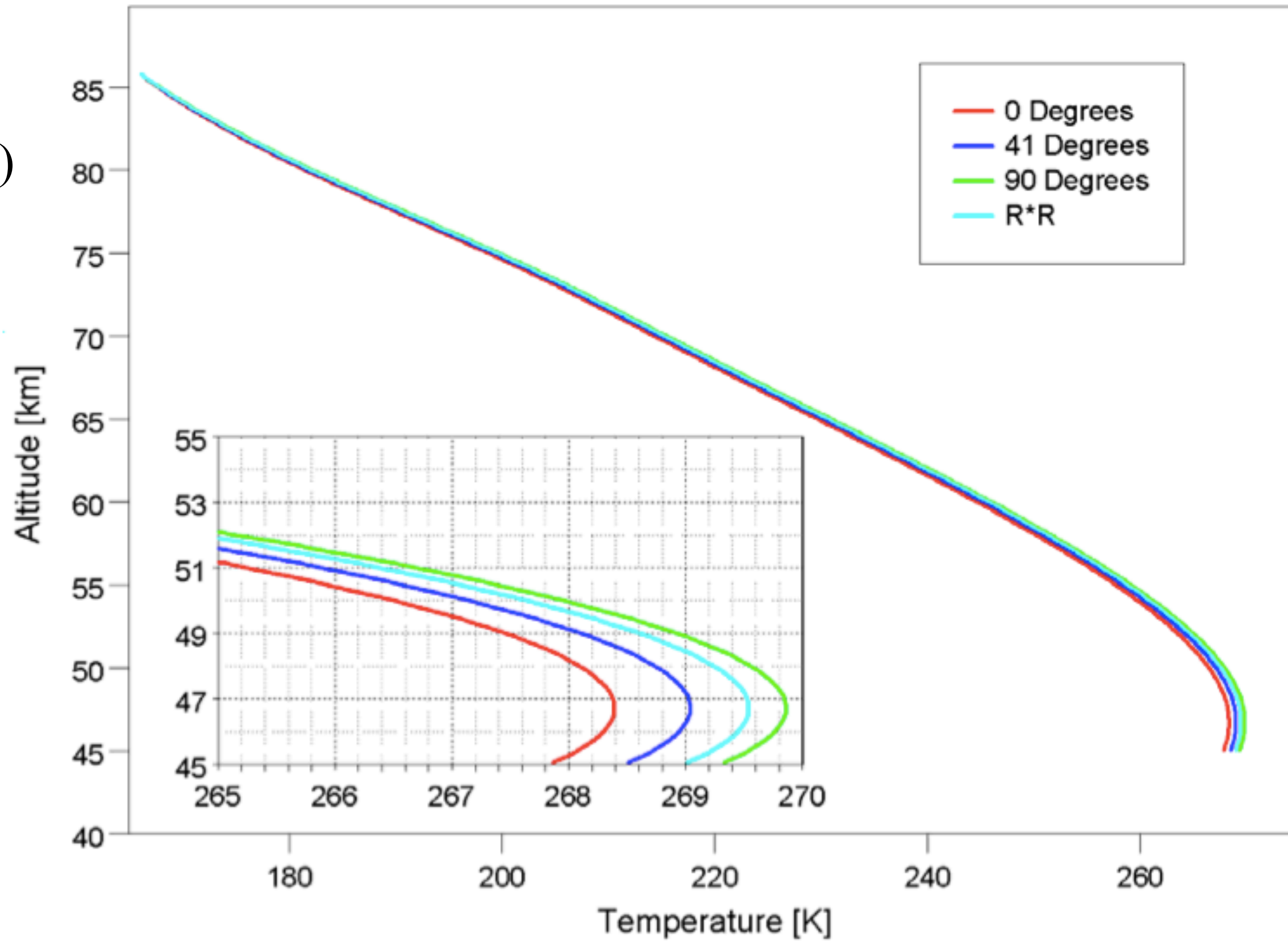
Gravitational Acceleration, $g(r)$

Start with
$g(r) = g(0)/r^2$

But, have Earth's rotation. Want $g(r)$ normal to surface.

Also have an oblate spheroid & nonuniform mass distribution
⇒ long. & lat. variations — see insert for effects.

Used $g(r)$ from the National Imagery & Mapping Agency for 41° N.

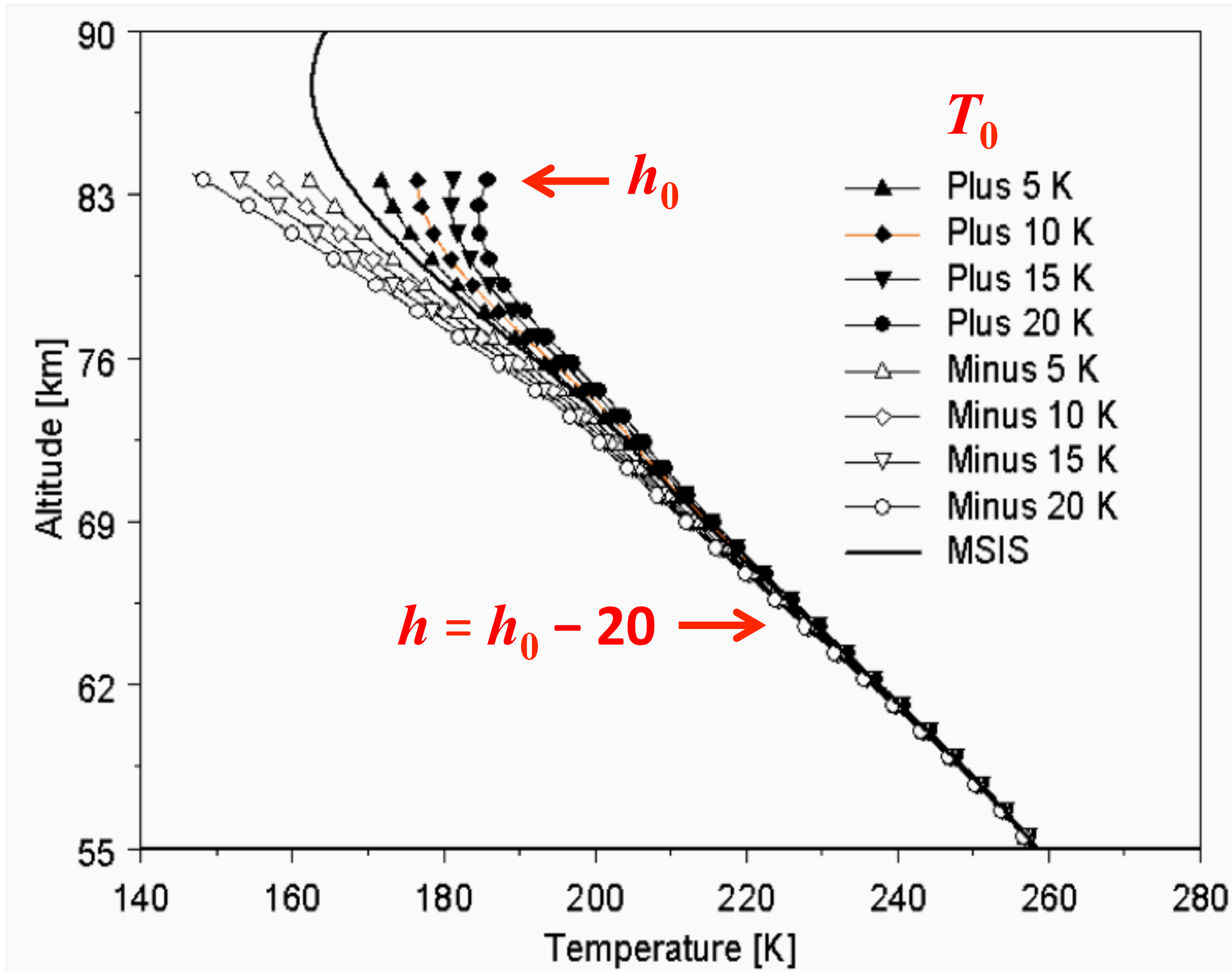


[Herron, 2004]

Impact of Error in T_0

An initial ±20 K error in T_0 at h_0 reduces to less than ±2 K after 20 km.

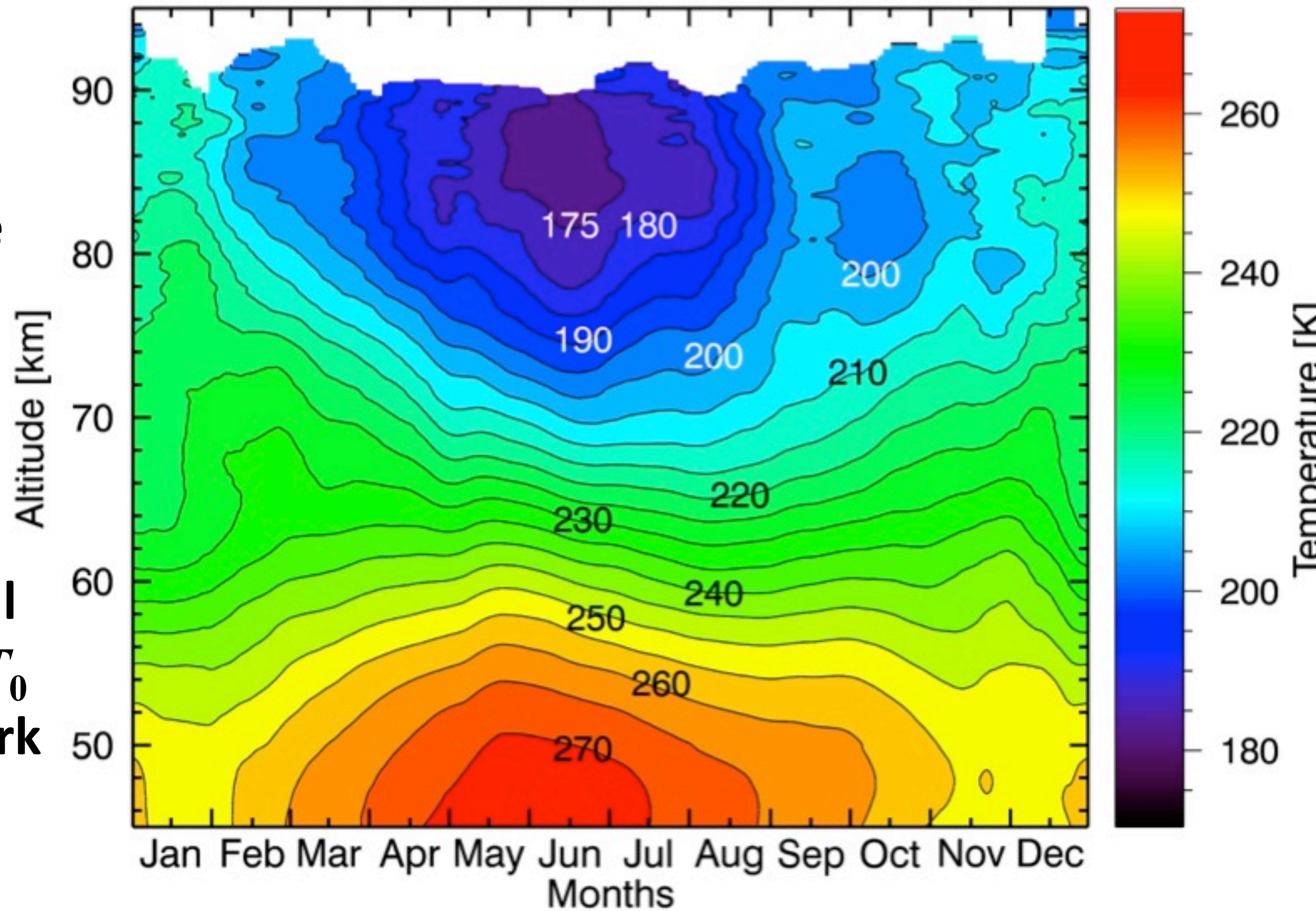
Sometimes ignore the first 10 to 20 km.



[Herron, 2004]

USU Temperature Climatology (1993-2004)

Initial values taken from CSU Na temperature climatology



However, for individual nights, this T_0 does not work because of variability

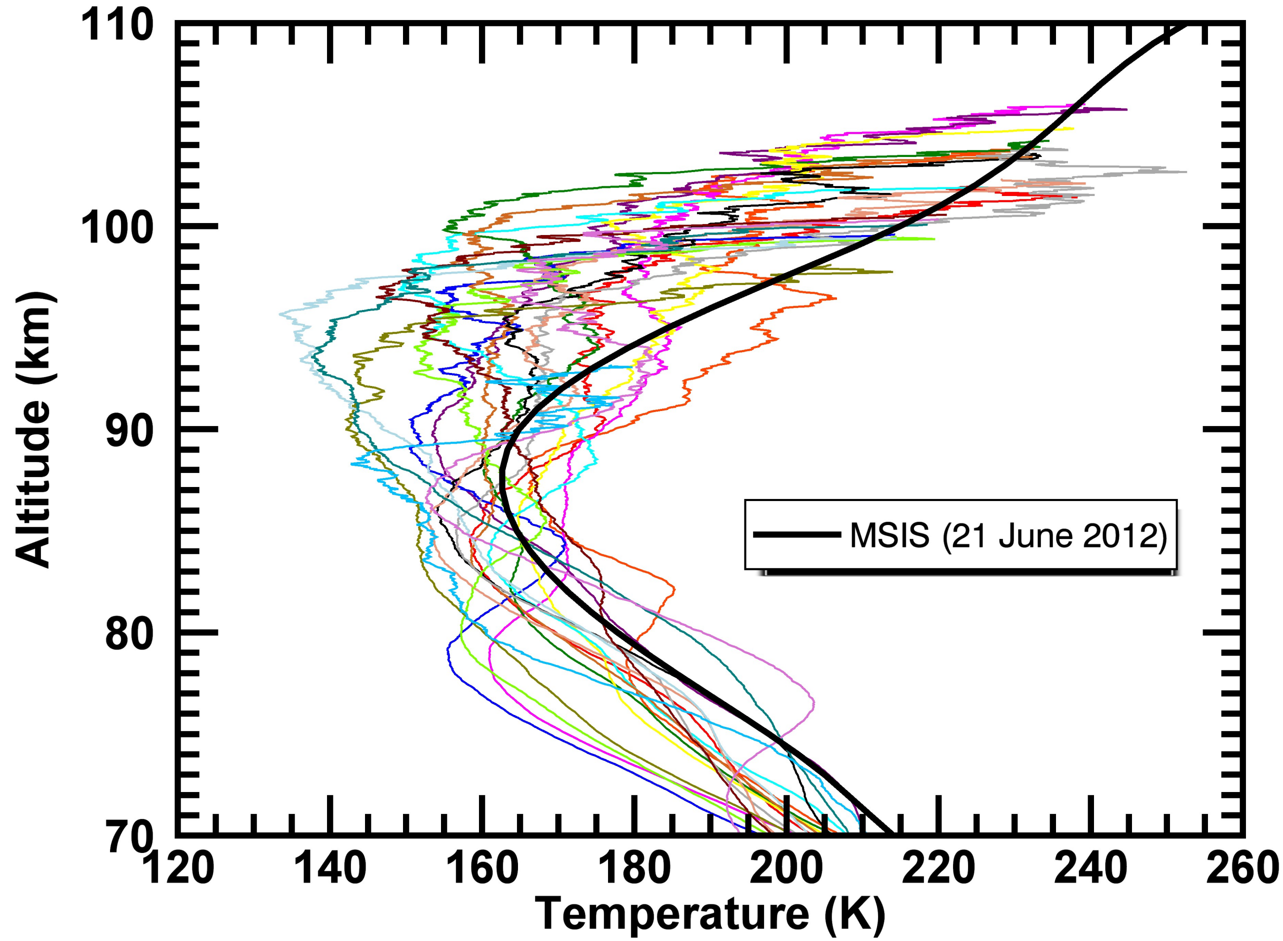
[Herron, 2007]

19 Nights in June/July 2012

Each profile is initiated from the MSIS value

Note that there are large oscillations

The initial temperatures appear to be too warm



Need another approach

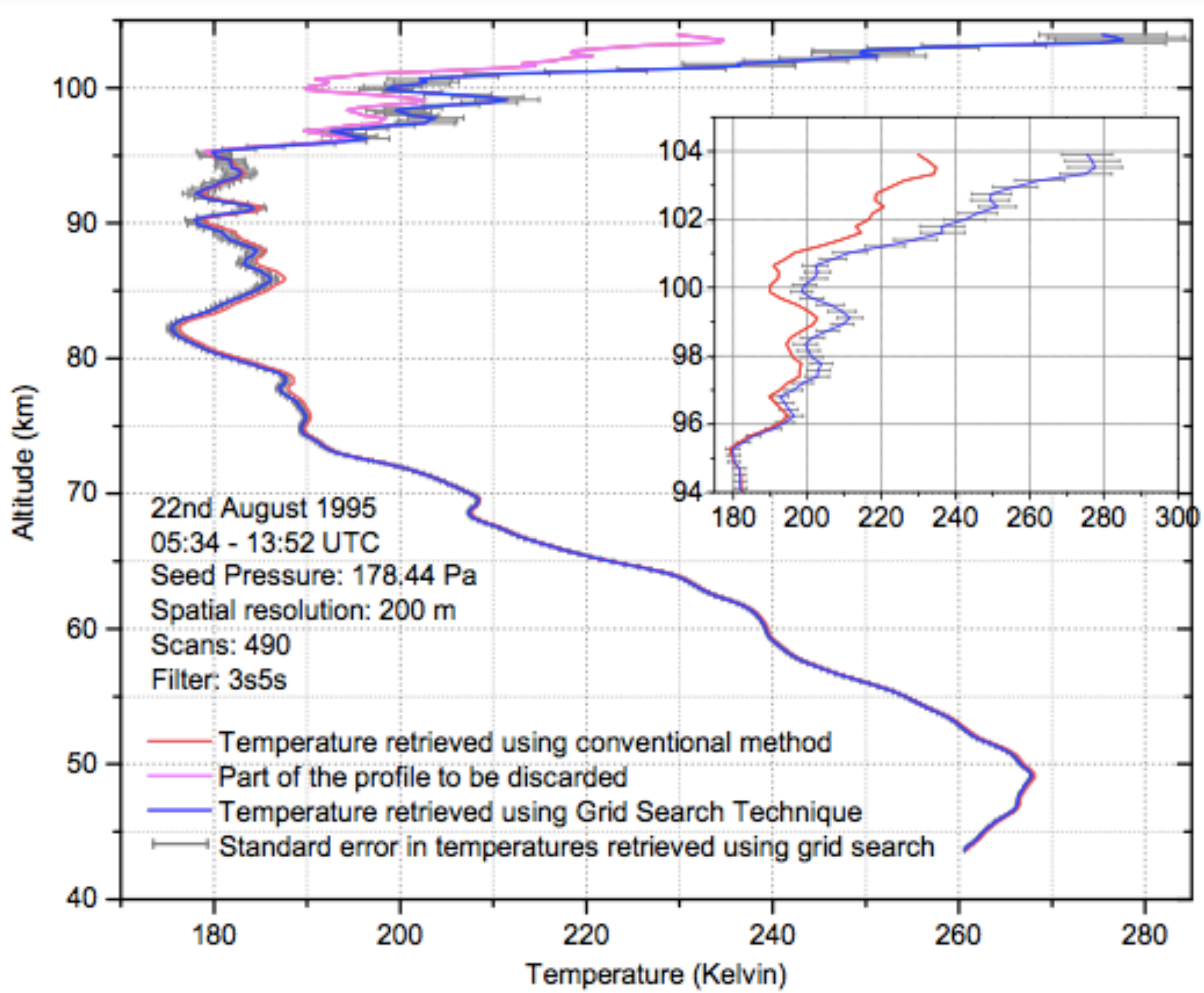
[Wickwar et al., Poster, CEDAR 2014]

Method of Khanna et al. (2012)

Grid Search Method
or
Forward Model

Start at the bottom and work up, but with constraints

See insert for differences in the top 10 km

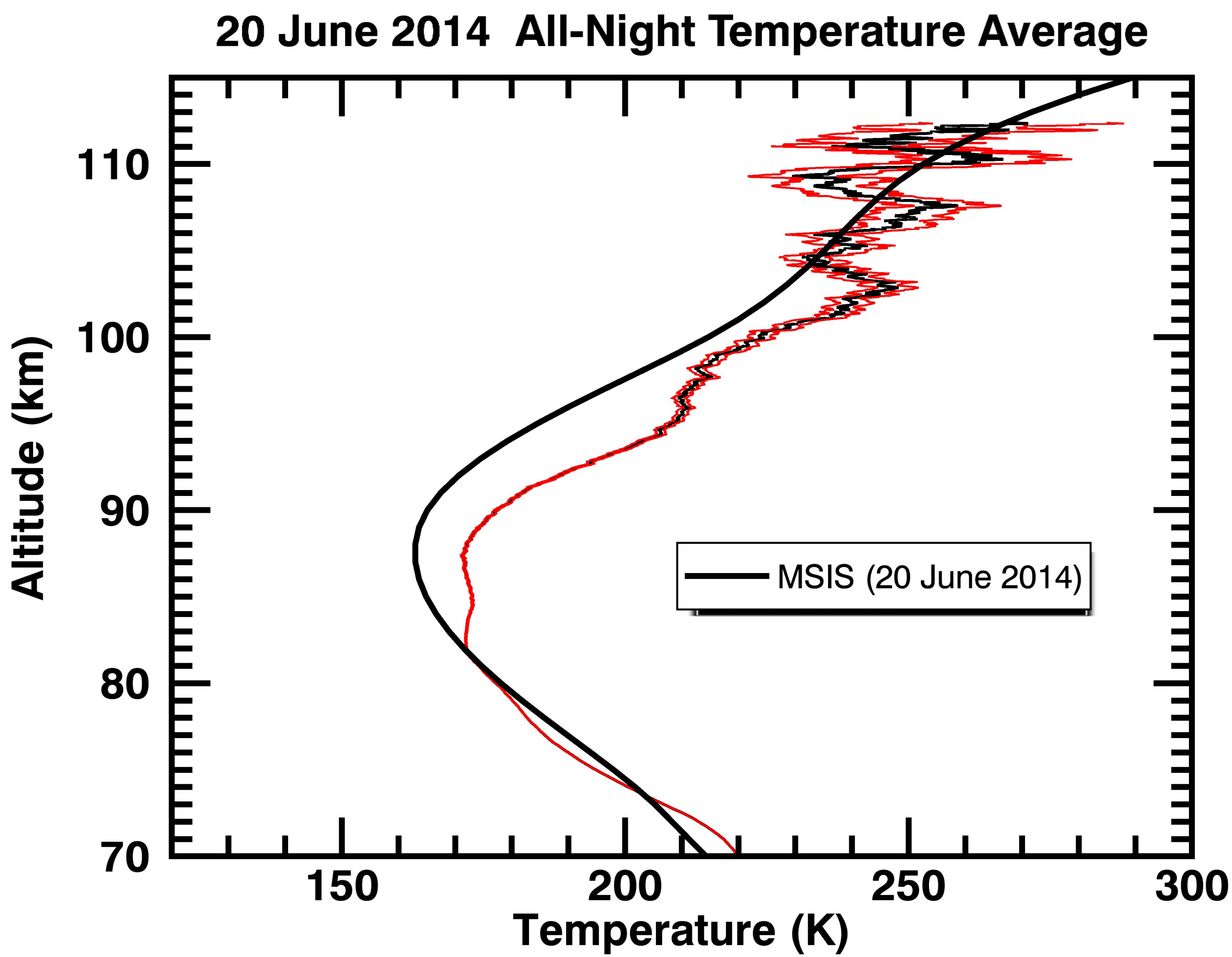


[Khanna, 2011]

Higher Alt. $T(h)$ Profile & Uncertainty

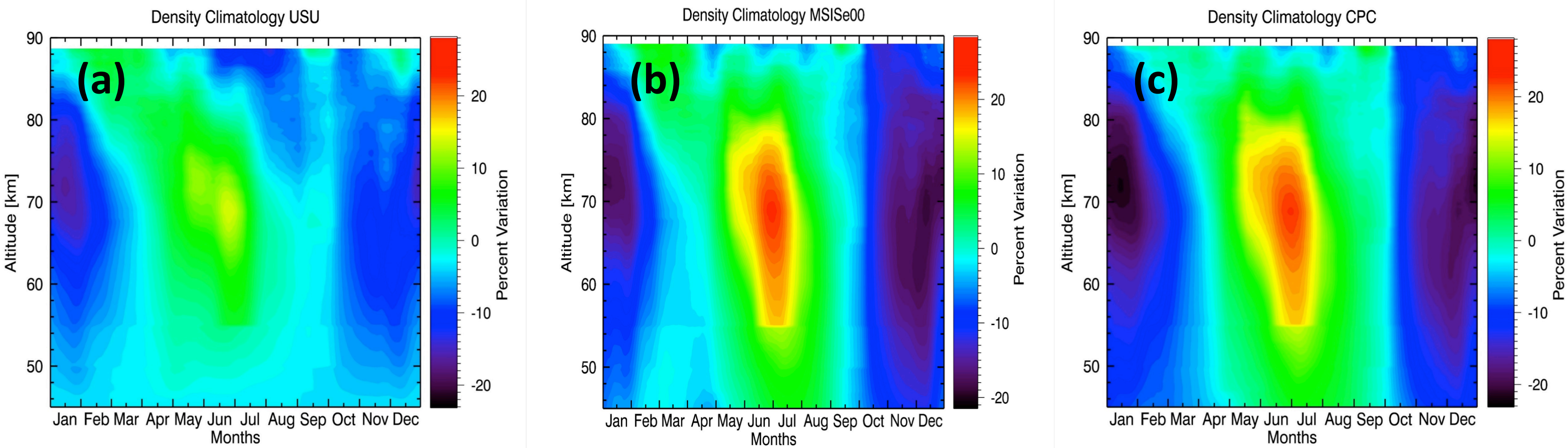
What should we use for the INITIAL temperature?

New Challenge: Neutral composition —
a) number and type of scatterers &
b) mean molecular mass



[Wickwar et al., Poster, CEDAR 2014]

Density Climatologies



- **Above, normalized relative densities from the lidar to (a) Unity (b) MSISE00 (c) CPC models at 45 km.**
- **Found percentage variation relative to the annual mean. They show seasonal variations and altitude features.**
- **In the future will extend the observations down to 15 km, thereby overlapping with observed densities and assimilative meteorological models. Will then give absolute densities up to ~120 km.**

[Barton et al., CEDAR 2014]

Summary

- **Temperatures**
  - Careful data handling (e.g., background)
  - Careful data reduction (e.g., gravitational acceleration)
  - Good initial temperature (e.g., known value);
    Khanna et al. (2012) forward model method
  - Composition at highest altitudes (a new effect)
- **Densities**
  - Careful data handling (e.g., background)
  - Normalize to density models
  - Below 30 km, could normalize to observations or
    assimilative meteorological models for absolute densities